mandate will unnecessarily boost the cost of DTV receiving equipment, retard technological development, and decrease market certainty.

If the full ACATS standard is adopted, broadcasters would be able to transmit programming in any of the standard's 18 video formats, and receivers and PC-TVs will need the sophisticated processing power to decode each of the 18 formats to be able to receive all digital programming, regardless of format.[43] Because the signal processing hardware is a major component of receiving equipment's total cost, requiring such sophistication in every set will inflate the cost of even low-performance, low-resolution equipment.[44] But without advanced processing power, receiving equipment would be unable to receive programming transmitted in more advanced formats, such as HDTV; when such programming is transmitted, the receivers would go black.[45]

The Grand Alliance has proposed that broadcasters be *required* to transmit a minimum amount of HDTV programming -- 25 hours per week, 15 of which are in prime time or weekend afternoons -- thus creating the need for all receivers to have the costly ability to decode the HDTV formats.[46] In fact, the Grand Alliance and other TV manufacturers have admitted that such a

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[43] William F. Schreiber, "Advanced Television Systems for Terrestrial Broadcasting: Some Problems and Some Proposed Solutions" (rev. December 22, 1994), *reprinted in Proceedings of the Institute of Electrical and Electronics Engineers*, vol. 83, no. 6 (June, 1995) ("Proposed Solutions"), Exhibit 6 hereto, at 963.

[44] *Id.* at 965.

[45] Grand Alliance Reply, at 33.

[46] Comments of the Digital HDTV Grand Alliance on Fourth NPRM, MM Dkt. No. 87-268 (filed November 20, 1995), at 5.

requirement would be necessary to prod consumers to purchase HDTV-capable equipment in spite of its significant cost [47]

Aside from costs, FCC adoption of all 18 formats will impede technological innovation by requiring improvements to any element of those formats to proceed through the regulatory process The more streamlined the standard adopted by the FCC, the easier it will be to improve upon it through voluntary industry action rather than a resource-draining regulatory proceeding.

Finally, if consumers must choose between paying the inflated price of HDTV-capable receiving equipment or paying less for TVs that are incapable of receiving all programming, some consumers may choose (or have no financial alternative other than) to forego HDTV programming to save money on their receivers. Such fragmentation of the receiver market will deny broadcasters and advertisers the certainty that the most advanced programming is reaching the widest possible audience and the uncertainty in turn will slow the growth of HDTV [48]

In short, while components of the ACATS standard might serve the public interest, the video formats will not If the Commission adopts a standard for digital broadcast television, it should seize this opportunity to make the standard good enough to stand the test of time.

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[47] Comments of James E. Carnes on behalf of the Grand Alliance, MM Dkt. No. 87-268, FCC *en banc* hearing, (December 12, 1995) at 4 Comments of Hitachi America, Ltd. on Fourth NPRM, MM Dkt. No. 87-268 (filed November 20 1995) at 4-5

[48] "Economic Considerations," Exhibit D to CICATS Comments, at 6, 8.

## III. THE COMPUTER INDUSTRY'S REFINEMENT OF THE ACATS STANDARD IS SUPERIOR.

There is a better alternative for digital television than the ACATS standard. The computer industry has proposed a limited set of refinements to the ACATS standard that would bring vastly improved results to consumers at lower costs. These refinements are set forth in detail in the CICATS Comments,[49] and are incorporated herein by reference.

If the Commission adopts a standard for DTV broadcasting, Compaq would propose that the standard reflect the refinements CICATS has proposed. Specifically, any standard the Commission adopts should be a simplified, base-line standard utilizing most of the ACATS standard's specifications, *but* replacing its 18 video formats with the following elements: (1) 480 vertical lines, (2) progressively scanned only, (3) with broadcaster-determined (*i.e.*, unspecified) picture aspect ratios, (4) square spacing of pixels, and (5) temporal layering for variable picture rates consistent with computer applications.[50]

In addition, as CICATS has proposed in detail, any standard that is adopted should be free of the restrictions ACATS has placed on the ability of

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49 CICATS Comments, at §§ III-IV

50 An acceptable set of picture rates that could be achieved with temporal layering would be 24 Hz, 36 Hz, and 72 Hz. *See* "Technical Exhibit," Exhibit B to CICATS Comments, at 5, 11; Gary Demos, "Temporal and Resolution Layering in Advanced Television," submitted with Comments of DemoGraFX on Fifth NPRM in MM Dkt. No. 87-268. In the alternative, picture rates of 24 Hz, 60 Hz, and 72 Hz, which would be more costly for consumers, but perhaps be more familiar to broadcasters, would be acceptable to Compaq.

MPEG-2 to "layer" data, thereby providing broadcasters the ability to enhance programming, *e.g.*, to provide HDTV programming, if demand is sufficient. Finally, the standard should be upgraded with an improved bit error correction mechanism developed by the industry when one is finalized, but the Commission need *not* postpone adoption of the standard pending that improvement.

The computer industry's proposed refinement of the ACATS standard would provide high-quality SDTV for all consumers with digital receivers, and offer the flexibility and baseline technology to provide state-of-the-art 720-line progressively scanned HDTV for those who were willing to pay for more sophisticated equipment. It would lower consumers' costs and let the marketplace decide whether HDTV is worth its price. And it would enhance computer compatibility, and accelerate the introduction of advanced applications merging computers and digital television.

## CONCLUSION

In summary, Compaq believes the costs of a government mandated DTV standard greatly outweigh its benefits and that the market is best suited to develop an appropriate standard for digital television. Compaq therefore urges the Commission to refrain from adopting any DTV broadcast standard. If the Commission nevertheless determines that adoption of a more specific DTV broadcast standard is in the public interest it should adopt the proposed ACATS standard *only* with the refinements proposed by CICATS in its comments in this proceeding.

Respectfully submitted,

**COMPAQ COMPUTER CORPORATION**

By ______________________

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July 11, 1996

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# EXHIBITS

## LIST OF EXHIBITS

| | |
|---|---|
| Exhibit 1 | Written Testimony of Robert Stearns |
| Exhibit 2 | "A Video Compression Efficiency Analysis using Progressive and Interlaced Scanning" |
| Exhibit 3 | "Comparison Between Interlaced and Progressive Scanning Formats" |
| Exhibit 4 | "Progressive versus Interlaced Coding" |
| Exhibit 5 | Written Statement of Craig Mundie |
| Exhibit 6 | "Advanced Television Systems for Terrestrial Broadcasting: Some Problems and Some Proposed Solutions" |

TESTIMONY OF

ROBERT STEARNS,

SENIOR VICE PRESIDENT, TECHNOLOGY AND

CORPORATE DEVELOPMENT,

COMPAQ COMPUTER CORPORATION,

BEFORE THE

SENATE COMMITTEE ON COMMERCE, SCIENCE AND TRANSPORTATION

ON THE

ELECTROMAGNETIC SPECTRUM MANAGEMENT POLICY REFORM AND

PRIVATIZATION ACT

JUNE 20, 1996

TESTIMONY OF ROBERT STEARNS,
SENIOR VICE PRESIDENT, TECHNOLOGY AND
CORPORATE DEVELOPMENT,
COMPAQ COMPUTER CORPORATION,
BEFORE THE
SENATE COMMITTEE ON COMMERCE, SCIENCE AND TRANSPORTATION
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ELECTROMAGNETIC SPECTRUM MANAGEMENT POLICY REFORM AND
PRIVATIZATION ACT

JUNE 20, 1996

Good morning, Mr. Chairman and members of the Committee.

I'm Bob Stearns, Compaq Computer Corporation's Senior Vice President for Technology and Corporate Development ... and its Chief Technologist as well.

In years past, I have testified before Congress and the FCC on a variety of communications issues of importance, and greatly appreciate the opportunity to testify today.

Compaq is the world's largest supplier of personal computers and the fifth largest computer company in the world, with 1995 world wide sales of $15 billion.

I might point out that's more than the combined sales of the three largest TV networks.

We've built Compaq's market position with an emphasis on open and voluntary technical standards and with a constellation of strategic partnerships, such as with Microsoft, that have permitted us to create products that meet real consumer needs.

With that as background, here are Compaq's views on the Electromagnetic Spectrum Management Policy Reform and Privatization Act.

To begin, Compaq agrees with Senator Pressler that spectrum is a valuable resource that should be made available on terms flexible enough to encourage its most innovative and efficient use.

Outmoded, inefficient uses of spect··m -- such as analog NTSC[1] television broadcasting -- should be replaced as soon as feasible by uses that will better serve the marketplace and the public interest.

Those to whom spectrum has been entrusted have an obligation to invest in the future ... even if that means doing business in a new and unfamiliar way.

I should mention that Compaq remains noncommittal about whether spectrum currently used or reserved for broadcast television should be auctioned.

But we do believe that the day when this spectrum can be returned to the government for re-use will be postponed by years ... if the FCC adopts the proposed Grand Alliance standard for digital television broadcasting.

Let's take a minute to focus on the Grand Alliance proposal.

Compaq believes this proposal is flawed.

First, it is not a standard at all but an amalgam of all the different formats that were being developed by the companies that joined forces to form the Grand Alliance.

Second, contrary to the way it's often portrayed ... it is not a "best of the best" proposal nor is it flexible.

Instead, it's really a grab bag of 18 different *mandated* formats.

And several of these formats incorporate outmoded, inefficient, and non-computer-friendly technology.

Third, if adopted by the FCC, the Grand Alliance proposal will straight jacket the future of digital broadcasting by effectively forcing digital TV receivers to decode all 18 formats.

And that would not be in consumers' interests.

Why?

Because consumers would be forced to buy receivers capable of receiving all 18 formats ... including formats that may not deliver a discernible difference to their picture quality.

[1] National Television System Committee

What's more, think of the amount of processing power that will be needed to decode all of the formats.

Having to incorporate that processing power will significantly incr - ase the cost of those television receivers and hybrid PC-TVs that are about to hit the market.

Consumers will be forced to spend billions of dollars--needlessly.,

In fact, prohibitively high production costs may well keep digital TV receivers out of reach for average consumers and slow the rate at which digital broadcasting becomes viable.

At one time, the Grand Alliance technology may have been adequate for purely entertainment purposes.

But with the convergence of TVs and computers well under way, it is now obsolete.

And by the time -- many years from now -- that the average consumer is able to afford a set that can receive and decode all 18 formats ... the technology will have been surpassed by a whole new generation.

We all know that engineers are improving the capabilities of digital technologies relentlessly.

So why perpetuate obsolete technology for digital television when it's advancing so rapidly in all other industries?

It would be like forcing tomorrow's cars to use brake systems and suspensions from the 1980s.

Let's fast forward to the year 2000.

Under the trajectory set by the Grand Alliance, we see two undesirable consequences.

One, more than half of American viewers will continue to watch analog TV.

Two, valuable spectrum allocated for digital broadcasting will remain underutilized.

The year 2000 doesn't have to be this way.

Compaq sees an alternative ... a simpler, less-regulatory standard that would greatly reduce the cost of digital television receivers.

We know Senator Pressler's bill envisions the government not mandating a standard for digital broadcast television.

From where we sit ... that approach is vastly preferable to the government's mandating a standard with *18* different formats.

That said ... let me underscore that Compaq and other members of the Computer Industry Coalition on Advanced Television Service ("CICATS") oppose the FCC's adoption of the Grand Alliance standard.

If the FCC decides that it should adopt *any* standard for digital television, we propose a minimal, but liberally enhanceable, baseline standard.

Our baseline standard would provide greater flexibility to broadcasters and equipment manufacturers.

It would significantly lower consumers' equipment costs.

It would accelerate the use of spectrum for digital broadcasting.

And more quickly free up spectrum for reuse that is now used for analog broadcasting.

For the past several months, Compaq and other computer and software companies have been advocating an improved digital TV standard that combines the best elements of the Grand Alliance's proposal.

The result is a flexible base layer format that would produce a huge qualitative improvement over today's analog TV ... yet at a cost that's a fraction of what's expected under the Grand Alliance proposal.

Best of all, the computer industry's proposal would provide interoperability between computers and digital broadcasting ... and accelerate the roll-out of affordable, interoperable products and services.

You may be wondering why Compaq cares so much about a digital television standard.

The answer is that the convergence of PCs and TVs is making digital TV transmissions an important part of the National Information Infrastructure.

At least three major manufacturers -- Compaq among them -- have unveiled a new family of products that are best called "hybrid PC-TVs."

These devices will revolutionize the way Americans receive, store, and process interactive information, and provide limitless new opportunities for entertainment and education

This is not pie in the sky. It's ready to eat today.

PC-TVs are already on the market.

And in the near future, many of us will see our homes transformed into intelligent networked homes, with the PC as its nerve center.

For example, your living room PC-TV, with its advanced digital display, might offer a 60-inch screen and handle a variety of content that you've selected.

And a home local area network, modeled after the one at work, will enable a central home PC to drive displays in the study, the kitchen, the kids' rooms, and the family room

We envision your home having far more interactive and diverse communications links to the outside world--including voice and voice services, paging, videoconferencing, e-mail, online services, and Internet access.

And PC-TV hybrids will enable you to pull in digital content on demand, along with a wealth of information and services ... including sophisticated electronic commerce and banking ... telemedicine ... and distance learning.

If next-generation digital sets are less expensive and digital television is more computer friendly, this day will be here before you know it.

More consumers will be able to purchase digital receivers sooner, and digital TV will become a reality faster -- we believe 5 to 7 years faster under the computer industry single-format proposal.

Broadcasters will migrate to all-digital transmissions faster.

And spectrum can be returned for auction sooner.

If Congress wants to maximize the benefits and minimize the cost to consumers and taxpayers ... it should join us in discouraging the FCC from adopting the Grand Alliance's proposed digital TV standard.

**Thank you very much for your time. I'm happy to answer any questions you may have.**

2

# Comparison Between Interlaced and Progressive Scanning Formats

Prof. P. Delogne*

## 1 Background

The advent of digital television has reopened the debate about scanning formats, which seemed to be definitely closed since the early times of television. Interlaced scanning was first requestioned in the early development of compression techniques. For instance, it appeared to be a major source of problems for the development of hierarchical coding schemes[1] during the RACE/HIVITS project. Shortly after this, some consideration was given to this issue in the development of the MPEG-2 standard as well as in work carried out in the related ITU/CMTT-2 rapporteur's group on secondary distribution of TV/HDTV. Whereas it is fair to recognize that MPEG-2 slightly opened the door to progressive formats, it is clear that none of these projects took the risk of fundamentally requestioning the well established position of interlaced scanning.

In early 1994, in the frame of debates carried out by the FCC about the adoption of a digital television system for the United States, the american association of cinematographers took a very strong position in favour of progressive scanning. After recalling that the interlaced scanning format used for television is a considerable source of artefacts which would not exist with a progressive format, and that about 70 per cent of the picture material broadcast by television operators originate from unscanned films, the cinematographers conclusions were quite clear, though a bit abrupt : it would be stupid to adopt interlaced scanning for a digital TV broadcasting standard.

About at the same time, the Image Project Line (PL4) of the european RACE programme had initiated a debate on the interlaced/progressive issue, with however a different basic motivation, i.e. the convergence of the computer/multimedia and broadcasting industries. At present these business areas exclusively use the progressive format and the interlaced format respectively. Convergence toward a unique format seems unavoidable in the long term. PL4 decided to prepare a recommendation addressed to the outside world, to draw the attention on the problem and to recommend some realistic orientations for the near future. The adoption of the recommendation was somewhat delayed by a rather conservative reaction from some company in the broadcasting consumer electronics area. It nevertheless came out. Subsequently the HAMLET project was asked to undertake additional studies to clarify some remaining uncertainties. Several papers in this session

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[1] Hierarchical coding, upward-downward or HDTV/TV compatibility, multiresolution analysis, spatial scalability, frequency scalability are roughly equivalent terms to describe attempts to include the description of a lower-definition picture in the compressed bitstream

will present results of this investigation. The present paper has been prepared as a general introduction to the topic of scanning formats

## 2 Scanning as a sampling operation

The scanning system used by television systems analyzes moving pictures as a sequence of images called *frames* which are furthermore read line by line. The most obvious scanning system is the *progressive* one illustrated on figure 1, which describes an analysis with 50 frames/s and 576 active lines per picture height $H$. Progressive scanning actually corresponds to a two-dimensional sampling operation described by an orthogonal sampling grid in the $(y, t)$ plane, as shown on the figure.

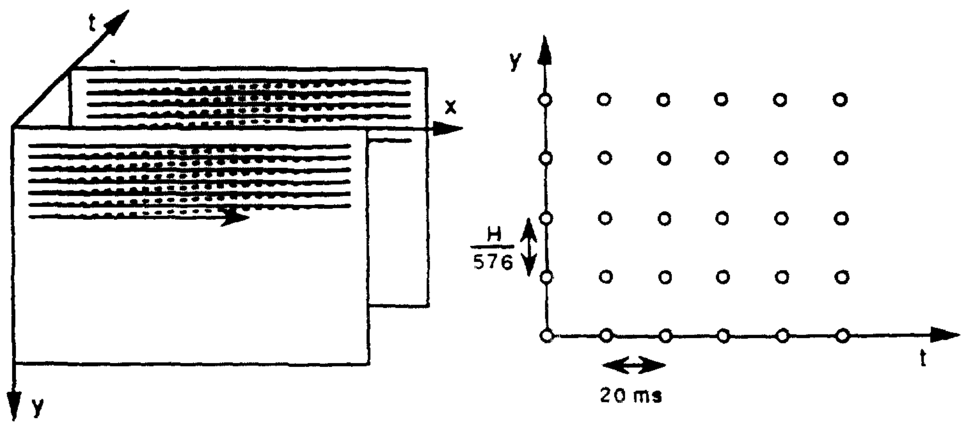


Figure 1: Progressive scanning system.

For reasons of bandwidth saving and of limitation of flickering effects, existing television systems use 2:1 *interlaced* scanning, whereby each frame is analyzed in two *fields* : odd fields contain odd lines and even fields contain even lines. Figure 2 illustrates the European standard with 25 frames/s and 576 active lines/frame. The corresponding sampling grid is now a quincunx as shown.

Of course, in digital television systems, the signal is also sampled in the horizontal direction, i.e. along the lines. The sampling pattern in the $(x, y)$ plane is most frequently orthogonal.

The theory of multi-dimensional sampling is somewhat more complex than for the one-dimensional case [1]. The spectrum of the analog signal is here aliased at the nodes of the conjugate network. If we denote by $\overline{v}_i$ the base vectors defining the structure of the sampling network in the $(x, y, t)$ space, the conjugate network is defined by base vectors $\overline{u}_j$ of the $(f_x, f_y, f_t)$ space, such that $\overline{u}_j \cdot \overline{v}_i = \delta_{ij}$. Figure 3 illustrates the conjugate networks for progressive and interlaced scanning in the $(f_t, f_y)$ plane. The peculiarities of multi-dimensional sampling as related to television scanning merit some comments. It should first be noted that, contrary to one-dimensional sampling, the aliasfree baseband is not uniquely defined. The baseband illustrated by the continuous-line rectangle on the left-hand side of figure 3 seems logical, but it is not the only possible choice. As a matter of fact, for a given conjugate network there is an infinite number of possible alias free

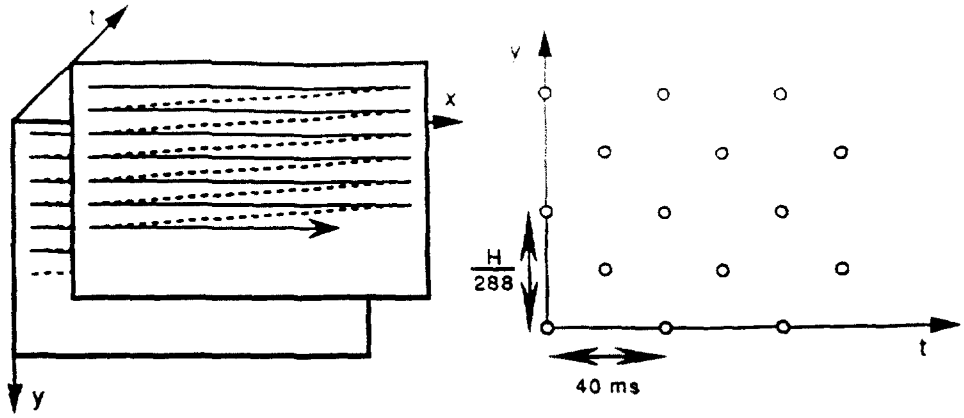


Figure 2: Interlaced scanning system.

basebands, even under the constraint of a maximum area for this bandwidth. This can easily be understood by comparing the aliased spectra with the visible part of tiles on a roof: given the network of tiles centers, there is an infinite number of possible shapes to assume complete coverage. The right-hand part of figure 3 illustrates three possible bandwidths for interlaced scanning.

In principle it is necessary to avoid aliasing effects by presampling filters. This means that a spatio-temporal filter should be placed ahead of the scanning system. The technical means to do this are extremely poor. It is possible to obtain some spatial lowpass filtering by defocusing the optical system in front of the camera. This adjustment is made experimentally so as to obtain the best subjective picture quality, representing a compromize between loss of resolution and aliasing effects. The camera spot remanence similarly performs some temporal lowpass filtering. It is clear that the spatio-temporal spectrum of television pictures is not very well defined and that complex spectrum shapes such as some ones shown on figure 3 represent purely theoretical concepts. The only sound statement in this regard is that the baseband spectrum is vaguely rectangularly shaped by the camera system. Image sequences currently exhibit considerable temporal aliasing.

Similarly, reconstruction filters are needed to eliminate the aliased spectra in the display process. The technical means available for this purpose, i.e. defocusing the display spot and increasing the spot remanence, are again very poor. Actually the human visual system, acting as a lowpass spatio-temporal filter, will play the main role in reconstruction filtering.

## 3 Psycho-visual effects

The human perception of pictures displayed on a screen depends on a number of external factors, among which the viewing distance, the screen brightness and the background lighting.

The eye roughly acts as a spatial lowpass filter, with some cutoff frequency expressed in cycles/degree. The main effect of the viewing distance is in the conversion from these

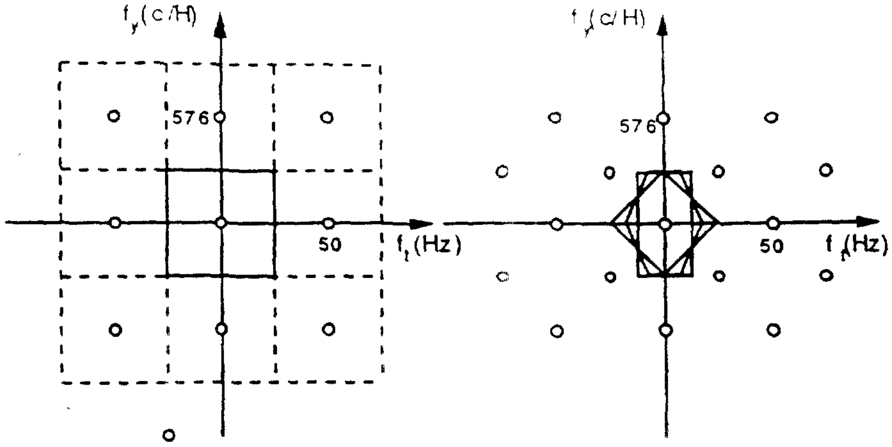


Figure 3: Conjugate network in the $(f_t, f_y)$ plane for progressive (left-hand side) and interlaced (right-hand side) scanning.

cycles/degree to the cycles/picture height in which spatial frequencies are currently expressed. The eye cutoff frequency is not uniform, being maximum in the foval area.

The human visual system also acts as a temporal lowpass filter. This phenomenon involves different layers in the global process, ranging from purely perceptual effects such as retinal persistence to interpretation by the human brain. It is almost sure that the brain cannot interpret more than a few different full pictures/second, but it can concentrate on some fast changing details (e.g. a tennis ball). One can dream about a television system which would capture only a few frames/s and would include, at some place in the global link, an effective temporal interpolation system so as to eliminate any purely perceptual impairment. One has to find the right frontier between dream and realism for such approaches. The dream assumes that the interpolation system can be as intelligent as the human brain. Realism dictates to take into account economically achievable pseudo-intelligent temporal interpolation techniques. For the time being, this probably does not go beyond the use of motion compensation without any picture content interpretation. Nevertheless, temporal interpolation (including its simplest implementations, such a the triple projection of each picture made in the cinema technique) has to be considered nowadays as an intrinsic part of the viewing problematic.

The artefacts resulting from scanning are essentially due to the poor characteristics of the antialiasing and reconstruction filters, as explained above. Interpolation can be used to compensate for insufficient reconstruction filters, i.e. to decrease the visibility of repeated spectra. It is of no use to eliminate aliasing errors due to insufficient filtering occurring ahead of scanning itself : this kind of error can be called *irreducible* . Artefacts related to scanning can easily be understood using spectral representations such as those of figure 3.

A preliminary remark should be made about the latter. The areas of the possible baseband for progressive versus interlaced scanning are in a ratio of two. It is not fair to make comparisons in these conditions. It is obvious that 50 Hz progressive scanning (P50) offers twice the possible temporal resolution of interlaced scanning, which transmits only 25 frames/s. Comparison with 25 Hz progressive (P25) is more reasonable. The latter is also interesting, in view of its relation to cinema

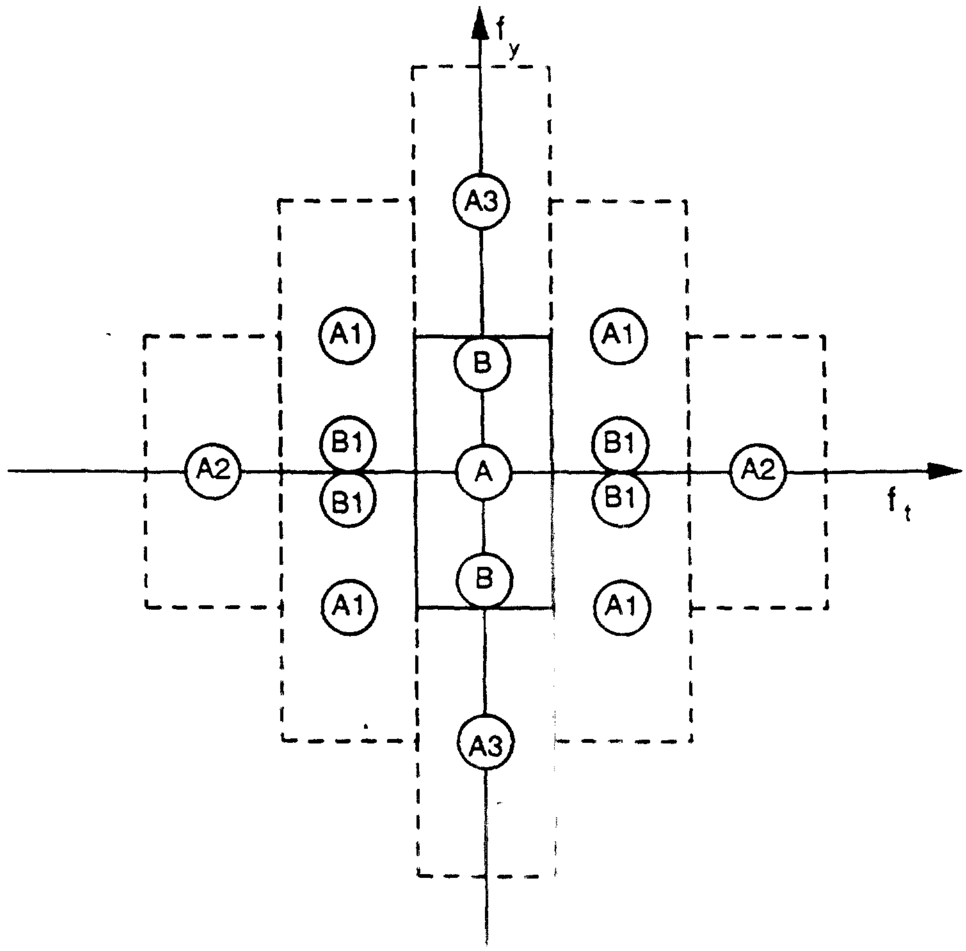


Figure 4: Aliasing effect for interlaced scanning.

Whatever the case, the well known artefacts of interlaced scanning are essentially due to the quincunx structure of the repeated spectra, which causes frequencies of the baseband to be aliased closer to the origin of the $(f_y, f_t)$ plane than for progressive scanning. Figure 4 can be used for this purpose. The following types of artefacts can occur :

1. Some frequencies present in the scene and located somewhere between A1 and B1 are mapped between A and B because of insufficient filtering ahead of the scanning process. This is the source of irreducible errors, such as wheels turning in the wrong direction, etc. P25 is not better than interlaced in this regard. Obviously, such effects are less likely for P50.

2. Another type of irreducible error is B1 being mapped to B. This area B1 corresponds to large-area luminance variations at 25 Hz, such as due to electroluminescent tube

lighting. Interlaced scanning is here better than P25, for which B1 is mapped to A, where the eye sensitivity is maximum. The corresponding problem for P50 is A2 being mapped to A, but this is less critical.

3. At the display side, the generally quite energetic area A being aliased in A1 is the cause of interline flicker and crenelated diagonal moving edges, which are major impairments of interlaced scanning. They can only be reduced by increasing the viewing distance. With P25, A would be aliased in B1 (large area flickering at 25 Hz) : this is obviously not acceptable and some temporal interpolation is absolutely needed. This problem is solved by projecting each picture three times in the cinema technique. For P50, the area A is aliased in A2 (large area flickering at 50 Hz) as it also is for interlaced : this is just acceptable and is being improved in recent techniques such as 100 Hz TV.

4. Area B corresponding to high-detail in the picture is repeated in B1 and causes large area flickering at 25 Hz. This is one of the major weaknesses of interlaced scanning in the absence of any temporal interpolation. Historically, it has been the reason why the vertical spatial resolution is reduced by a factor $K \approx 0.7$ below the maximum achievable resolution (288 c/H, i.e. 576 lines). $K$ is known as the Kell factor.

Globally, interlaced scanning suffers from a number of weaknesses due on the one hand to some irreducible aliasing errors and, on the other hand, to the difficulty of applying temporal interpolation techniques to this format to improve reconstruction filtering. It is currently admitted that the viewing distance for the interlaced format must be about twice larger than for P50 to achieve the same visual quality. Some people assert that P50 would be nearly as good as interlaced HDTV. As far as P25 is concerned, this format probably offers enough intrinsic temporal resolution for a very large class of picture material, as cinema as shown since a long time, but it cannot be displayed without some temporal interpolation. It is certainly a good candidate for the broadcasting of films, for which it has the appropriate frame rate.

# 4 Capture and display devices

The question of scanning formats cannot be discussed without devoting some consideration to the characteristics of capture and display devices and of their possible evolution.

Traditional cameras use a tube as the capture device, but CCD cameras are now available. Both can be used for progressive as well as interlaced scanning. The main problem with tubes is their relatively poor signal-to-noise ratio for progressive scanning as compared to interlaced. The difference is considerably reduced for CCD cameras, as shown on Table 1. This table was taken from [2] and shows figures for HDTV 1125 lines cameras. A difference is made between the nominal SNR and the effective SNR in camera operation, the latter taking into account the amplifier noise and line processing performed in the camera. In this table, "progressive" means P50. The gap between interlaced and progressive will further be reduced with new CCD techniques such as M-FIT CCD.

| Image Device | Tube | | CCD | |
|---|---|---|---|---|
| Scanning system | Interlace | Progressive | Interlace | Progressive |
| Signal bandwidth (MHz) | 30 | 60 | 30 | 60 |
| Nominal SNR (dB) | 47 | 38 | around 50 | 41-47 |
| Effective SNR (dB) | 34-38 | 25-29 | 37-40 | 29-37 |

Table 1: Effective SNR estimate of 1125 lines HDTV camera

Regarding displays, the development of HDTV is a driving force in research on alternatives to the classical cathode ray tube (CRT), also for TV display. New promising systems such as the *Active Matrix LCTV*, the *Digital Micromirror Device* and *Plasma Display Panel* present interesting behaviors for interlaced and progressive scanning formats as well. Some of these are intrinsically based on progressive scanning, the display of interlaced pictures requiring additional manipulations. It is likely that these new technologies will lead to consumer products in a relatively near future.

To conclude, it appears that capture and display devices are probably not among the most important obstacles to an evolution toward the use of progressive scanning.

## 5 Signal processing aspects

Various types of signal processing operations need to be performed in a digital TV chain. The acceptable degree of complexity is certainly not the same for operations performed in studios and in the user terminal, but this gap is now reduced with the advent of VLSIs for consumer products.

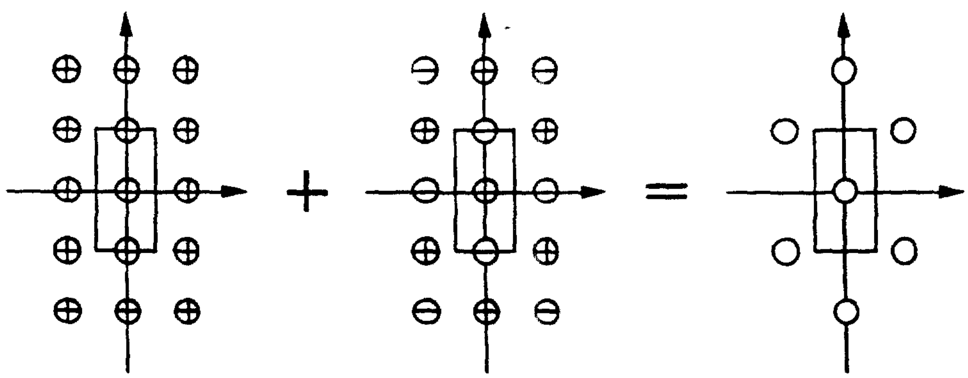

Figure 5: The spectrum of an interlaced signal as the sum of spectra of even and odd field sequences.

Before looking at various signal processing operations, we would like to recall an alternative view of interlaced scanning, as this can give some insight on basic difficulties of signal processing for this format. The spectral properties of interlaced scanning shown on figure 3 can be understood at the light of figure 5. An interlaced signal can be considered as the sum of two progressively scanned pictures, i.e. of the sequences of even fields and of odd fields. As can be observed on figure 2, the latter can be considered as due to two progressive scanning systems with half the number of lines, but with different sampling phases. The sampling phases result in plus and minus signs affecting the aliased spectra, half of which disappear in the summation. The quincunx repetition of spectra for interlaced scanning result from this quasi magic property. The merit of this presentation is to make clear that nearly any classical signal processing operation performed inside a field or even on a sequence of fields with the same parity would be theoretically illegal, because it operates on a signal which has been sampled at half the Nyquist rate in the vertical direction. Interlaced scanning is a considerable source of difficulties for picture processing, including for coding, because spatial and temporal operations are no longer independent.

## 5.1 Spatial filtering

This is one of the most current operations, which has to be performed in a lot of more complex processes (see below). We are here concerned with the vertical direction. There is no difficulty for filtering progressively scanned pictures, since it is perfectly justified to apply a spatial digital filter operating inside frames. With interlaced scanning however this is a theoretically illegal operation. In principle, spatial filtering in the vertical direction now requires to operate on several fields. A satisfactory way of proceeding has been found [3, 4], but it practically involves the use of a quite complex deinterlacer (see below). This may not be acceptable from the cost point of view in many applications, since several field memories would be needed. In practice, intra-field filtering is sometimes used, but this should be done with much care, taking into account the summing properties illustrated on figure 5.

## 5.2 Temporal interpolation - Motion estimation/compensation

Temporal interpolation is required in a number of processes. The classical technique for interpolation is to insert zeroes and lowpass filter the result. This method is nearly never used for the temporal interpolation of TV signals, even with progressive scanning, as this would need to operate on a rather large number of frames. A much more efficient technique is to use motion information for interpolating between two successive frames. Using three frames can provide better results in areas being covered or discovered by the motion of foreground objects.

With progressively scanned signals, there is no fundamental difficulty in the motion estimation, even with sub-pel accuracy, as well as for the interpolation itself. With interlaced scanning, estimating motion between two fields, either with the same parity or with opposite parities, frequently provide erroneous motion vectors. This is not surprising since vertical sampling at half the Nyquist rate provides fields which contain only 50 per cent of the information. This is true for full-pel and sub-pel accuracy as well. Again, the right way of proceeding is known [3, 4], but it is quite complex.

## 5.3 Interlacing - deinterlacing

Interlacing is generally not a complex operation. Conversion from P50 to interlaced is elementary. High-quality conversion from P25 to interlaced supposes temporal interpolation and can be done with moderate complexity. A very cheap alternative is to merely use the odd/even lines of a P25 frame as the odd/even fields of the interlaced format. This is actually what is done for telecinema, and the result is not so bad.

Deinterlacing is much more complex. Producing P50 or P25 by mere vertical interpolation inside fields is a theoretically illegal operation. It may yield more or less acceptable results only for pictures shot with a rather low Kell factor. For higher-quality pictures, it is necessary to resort to techniques using motion information. Satisfactory solutions have been found [3, 4], but they are quite complex and should probably be reserved to professional studios. The utilization of such complex techniques at the receiver side does not seem realistic today.

## 5.4 Still picture, slow motion, chroma key

These operations are currently performed in studios, but they are of interest also for consumer equipment (e.g. recorders) and in multimedia production.

*Still picture.* If the picture to be displayed in still-mode is progressive, this process is automatic and reduces to an editing problem. If the incoming signal is interlaced an interpolation is logically needed. The quality of the deinterlacing algorithm is in this case more critical because artefacts are actually clearer than what can appear in motion.

*Slow Motion.* Slow motion can be regarded as a conversion to a higher frame rate. Conventionally in the interlaced world, slow motion replay has been achieved by simple field repetition. This process gives rise to undesirable jerky motion effects. To overcome these problems high-quality slow motion algorithms recently projected are all based on a high-quality deinterlacer, specifically projected or adapted to this purpose. Typically the whole process is a cascade of such deinterlacer followed by a temporal interpolation, where the number of intermediate interpolated pictures depends on the desired target frame-rate. The deinterlacer step is obviously skipped for a progressive input.

*Chroma-keying.* Digital chroma-keying is intended to replace the historical analog process based on the use of the blue component to separate elements from a scene. Basically good performances in isolating objects from an image to overlap it on another are achievable only through good region and contour detection, surely easier in progressive scanned picture than in blurred (since field-merged) interlaced picture. Within the researches currently under development progressive reference material is always considered.

## 5.5 Frame-rate conversion

This conversion can be used at both transmitter and receiver sides. It primarily concerns conversions between :

1. 50Hz/59.94Hz/60Hz : compatibility between European, Japanese and American standards.

2. 50Hz/100Hz : this is a means to improve video domestic quality still using an interlaced TV screen. Due to this advantage it has already found a place in the market with pure repetition of fields. Some upgrades to these elementary algorithms, making use of motion estimation are already available. This new solution is provided by the cascade of a deinterlacer, a temporal interpolator and a reinterlacer, in order to obtain an interlaced 100Hz sequence where only every fourth picture is an original. The complexity of the algorithm presently fits better with studio or broadcasting application.